Preface

Organic electroluminescent devices have been one of the most attractive research topics in Material Sciences during the last two decades. The attraction and fascination of this field stem mainly from the interdisciplinary nature of the approach which includes synthetic and physical chemistry, device physics and electrical engineering. Particularly appealing and inspiring is the palpable link between both basic and applied science and an immense industrial and commercial interest in its applications.

When surveying the progress of research and development in electroluminescent devices, it becomes obvious that such emerging technologies always develop by way of competition with existing technologies which are themselves undergoing continual optimization. One is thus “shooting at moving targets”. The strong competition between the as yet progressing “conventional” semiconductor technology and the “new” field of organic electronics applications forms the backdrop for the development of organic electroluminescent devices. Moreover, the competition is not only focused on scientific problems such as materials design and optimization, device structure and performance (including power consumption and lifetime/stability), but close to market also issues such as large scale production, manufacturing costs and market prices become important. Despite all these problems the commercialization of organic electroluminescent devices is forging ahead with impressive speed and capacity. The process is driven globally by numerous large multinational companies as well as small start-up companies.

Research into organic electronic materials was dominated until the 1980s by the search for “synthetic metals” with a high electrical conductivity. In this endeavor, oxidatively or reductively doped organic materials were most favored. Thereafter the electronic and emissive properties of neutral, undoped organic semiconductors also became focal points of major scientific activities. The spearhead of the organic electroluminescence research was achieved by Ching Tang’s group at Kodak in the late 1980s. Their impressive contributions to organic electroluminescent and photovoltaic devices paved the way for all the subsequent progress. Some years later Richard Friend’s group in Cambridge performed pioneering work which introduced light-emitting semiconducting polymers as an additional class of promising emissive organic materials for electroluminescent devices.
New technology requires new or improved materials. For example, the pioneering OLED work of the Friend group published in 1990 used low quality, so-called “precursor poly(phenylene vinylene)” (PPV) as the emissive material. Their initial, very promising findings then stimulated a wealth of synthetic work. After 15 years of materials improvement soluble PPV-type materials with high purity, structural regularity and excellent OLED performance are now commercially available. No doubt, the synthetic protocols employed to generate these polymers are crucial for achieving reasonably high molecular weights and structural perfection, as the presence of defects has major and usually deleterious effects upon the performance of OLED devices.

However, the competition between different concepts is not limited to the chemical structure and molecular weight of the organic materials. Also the techniques for their processing are a key factor. While low molecular weight organic materials are commonly processed by well-established ultra-high vacuum techniques (MBD, PVD, and CVD) as widely used in the production of inorganic semiconductor devices, wet processing is an alternate procedure for the deposition of semiconducting oligomers and polymers, e.g. by spin casting, doctor blading, and screen or inkjet printing. Solution based processing techniques seem pivotal to the search for low cost fabrication alternatives. The wet processing of semiconducting materials for OLED devices, however, is by no ways a trivial task, so that the solubility behavior of the solution-processed components assumes particular attention. Since multilayer devices are the mostly favored OLED design, either a strict orthogonality in the solubility of different materials or a subsequent cross-linking of previously solution-deposited layers is required.

The complexity of the competition, however, does not end with this example. Much of the industrial interest in organic electroluminescent materials sprang from the hope that a future display technology would be mainly based on organic light emitting diodes (OLED) and was derived from envisaged advantages as high brightness, wide viewing angles and low cost. But meanwhile also liquid crystal-based displays (LCD) were tremendously improved. It is by no means clear which technology will finally win the contest and whether electroluminescence of organic materials will be used primarily in OLED displays or for solid-state lighting applications.

Research into OLEDs has generated important scientific problems, such as how to control not only the emission wavelength so as to obtain full color red/green/blue (RGB) OLED devices, but also the migration of excitations within or between individual molecules, the balancing of the concentrations of charge carriers, the design of optimized interfaces between organic layers and electrodes, etc. Important criteria, hereby, are a maximum power efficiency and lifetime/stability of the resulting OLED devices. The introduction of transition metal-based electrophosphorescent emitters defined a further milestone towards technologically relevant device efficiencies. The enormous progress made in the application of triplet emitters has initiated a new round of OLED research. Again, the device optimization (performance-lifetime-stability) is the key challenge, e.g., a combination of a maximum device performance with sufficient lifetimes.
As a next step, technological problems resulting from large scale fabrication of devices are at the focus of efforts towards a commercialization of OLED devices. It is important to note that LCD and OLED display panels are designed upon similar principles since behind the active organic layers, both require driving electronics based on thin-film transistors. This similarity suggests that the commercialization of OLED devices is not only guided by the device performance, but to a great extent by fabrication technology and production costs.

The concept of “Organic Electroluminescent Devices” follows the above outlined landscape. The logical place to begin is by first covering the background against which all research into OLEDs occurs – the existing but still evolving technology of inorganic LEDs, which is the immediate competitor against which OLEDs must seek to establish themselves. We therefore start with an introductory chapter by Fred Schubert on inorganic semiconductors for LEDs.

Obviously before one can hope to optimize OLEDs one needs to understand the scientific fundamentals behind their operation. So we then proceed with contributions from two of the world’s leading experts on the photophysics of organic semiconductors into the fundamental issues involved in emission from organic materials. Heinz Bässler provides an overview of the photophysics of emissive organic materials, while Richard Friend presents a discussion of his recent work into one of the key topics in the physics of OLEDs: the electronic processes at polymer heterojunctions. This leads logically on to considering how one goes about optimizing OLEDs, which is covered by two contributions which between them illustrate many of the methods being used to achieve this vital goal. Alan Heeger describes the various research approaches being investigated at Santa Barbara, while Shuit-Tong Lee presents some of the recent work from his group at Hong Kong.

Having established the fundamentals of OLEDs and their development, we next turn to consider the materials that are to go into them and their processing. One needs to know not only what types of materials have been or could be used in OLEDs, but also how their properties can be controlled by synthetic design. Here we have overviews of the synthesis of two of the main components in OLEDs. Andrew Grimsdale describes the main classes of electroluminescent polymers, with an emphasis on how their properties and device performance can be optimised by synthetic design, while Yasuhiro Shirotani reviews materials for use as charge-transporting and hole-blocking layers in multilayer devices. Dendrimers are a class of material which are generating increasing interest in all areas of materials science and John Lupton provides us with a review of their use in OLEDs. Finally Klaus Meerholz describes some of his exciting work which beautifully demonstrates how the intended processing of materials must be an integral feature of their design.

Finally, novel directions are continually opening up in OLED research and development, and so we end with accounts of three of the most exciting of those that have appeared in recent years. An optimal material for an LED would combine the advantages of inorganic and organic materials, and so Andrey Rogach provides an account of work into inorganic/organic hybrid materials, which seek to achieve this. A major limit on the performance of OLEDs has always been
that the energy of the majority of excited states, the triplets, was wasted. Dieter Neher describes how electrophosphorescent devices based on triplet emitters are being developed which utilize this resource and so offer the prospect of much higher device efficiencies. Finally, the ultimate development of OLED technology would be to make an electrically pumped organic laser diode and so we conclude with a contribution from Uli Lemmer on the work being done on organic semiconductor lasers which aims to cross that final frontier.

We would like to express our gratitude to Martin Ottmar at Wiley-VCH for inviting us to bring this exciting field of research to a wider audience, to all our distinguished contributors for their efforts, and especially to Andrew Grimsdale for his assistance in coordinating the project.

Mainz and Wuppertal
November 2005

Klaus Müllen and Ullrich Scherf